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Patentanmeldung Nr. | Patent application No. | Demande de brevet n°

99307686.8

Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
p.o.

Hatten

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THE HAGUE, 07/06/00
LA HAYE,LE

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Page 2 de l'attestation

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Lithographic method & apparatus

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LITHOGRAPHIC METHOD & APPARATUS

The present invention relates to a method and apparatus, in particular for microlithographic exposure. More particularly, the invention relates to the application of such a method in a lithographic projection apparatus comprising:

a radiation system for supplying a projection beam of radiation;

a first object table provided with a mask holder for holding a mask, and connected to first positioning means;

a second object table provided with a substrate holder for holding a substrate, and connected to second positioning means;

a projection system for imaging an irradiated portion of the mask onto a target portion of the substrate.

For the sake of simplicity, the projection system may hereinafter be referred to as the "lens"; however, this term should be broadly interpreted as encompassing various types of projection system, including refractive optics, reflective optics, and catadioptric systems, for example. The radiation system may also include elements operating according to any of these principles for directing, shaping or controlling the projection beam of radiation and such elements may also be referred to below, collectively or singularly, as a "lens". Any refractive, reflective or catadioptric elements in the radiation or illumination systems may be based on a substrate of glass or other suitable material, and may be provided with either single- or multi-layer coatings as desired. In addition, the first and second object tables may be referred to as the "mask table" and the "substrate table", respectively. Further, the lithographic apparatus may be of a type having two or more mask tables and/or two or more substrate tables. In such "multiple stage" devices the additional tables may be used in parallel, or preparatory steps may be carried out on one or more stages while one or more other stages are being used for exposures. Twin stage lithographic apparatus are described in International Patent Applications WO98/28665 and WO98/40791.

Lithographic projection apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In such a case, the mask (reticle) may contain a circuit pattern corresponding to an individual layer of the IC, and this

pattern can then be imaged onto a target area (die) on a substrate (silicon wafer) which has been coated with a layer of photosensitive material (resist). In general, a single wafer will contain a whole network of adjacent dies which are successively irradiated through the reticle, one at a time. In one type of lithographic projection apparatus, each die is irradiated by exposing the entire reticle pattern onto the die in one go; such an apparatus is commonly referred to as a waferstepper. In an alternative apparatus - which is commonly referred to as a step-and-scan apparatus - each die is irradiated by progressively scanning the reticle pattern under the projection beam in a given reference direction (the "scanning" direction) while synchronously scanning the wafer table parallel or anti-parallel to this direction; since, in general, the projection system will have a magnification factor M (generally ≤ 1), the speed v at which the wafer table is scanned will be a factor M times that at which the reticle table is scanned. More information with regard to lithographic devices as here described can be gleaned from International Patent Application WO 97/33205.

In one form of microlithography, a mask defining features is illuminated with radiation from an effective source having an intensity distribution at a pupil plane corresponding to a particular illumination mode. An image of the illuminated mask is projected onto a resist-coated semiconductor wafer.

Problems with the prior art include that in the semiconductor manufacturing industry there is increasing demand for ever-smaller features and increased density of features. In other words the critical dimensions (CDs) are rapidly decreasing and are becoming very close to the theoretical resolution limit of state of the art exposure tools such as steppers and scanners as described above. One solution to this problem is to upgrade the optics of the machine or indeed replace the entire machine. A second possibility is to use masks which include so-called "assisting features". These are features smaller than the resolution limit of the exposure tool so that they will not print on the wafer, but their presence near features to be imaged produces diffraction effects which can improve contrast and sharpen fine features. However, neither of these methods is entirely satisfactory and they can also prove expensive.

It is an object of the present invention to alleviate, at least partially, at least

some of the above problems.

Accordingly, the present invention provides a method of imaging a pattern onto a substrate provided with a layer of energy-sensitive material, comprising the steps of:

performing a first exposure to image partly said pattern;

performing a second exposure to image partly said pattern,

wherein at least one of said first and second exposures is performed using an illumination mode having a substantially dipolar intensity distribution..

The method of the invention enables lithography to be performed with reduced feature size and/or improved processing parameters such as exposure latitude, Mask Error Factor (MEF), depth of focus and proximity effects, without improved optics and without using diffraction- assisted masks.

In a manufacturing process using a lithographic projection apparatus according to the invention, a pattern in a mask is imaged onto a substrate which is at least partially covered by a layer of energy-sensitive material (resist). Prior to this imaging step, the substrate may undergo various procedures, such as priming, resist coating and a soft bake. After exposure, the substrate may be subjected to other procedures, such as a post-exposure bake (PEB), development, a hard bake and measurement/inspection of the imaged features. This array of procedures is used as a basis to pattern an individual layer of a device, e.g. an IC. Such a patterned layer may then undergo various processes such as etching, ion-implantation (doping), metallisation, oxidation, chemo-mechanical polishing, etc., all intended to finish off an individual layer. If several layers are required, then the whole procedure, or a variant thereof, will have to be repeated for each new layer. Eventually, an array of devices will be present on the substrate (wafer). These devices are then separated from one another by a technique such as dicing or sawing, whence the individual devices can be mounted on a carrier, connected to pins, etc. Further information regarding such processes can be obtained, for example, from the book "Microchip Fabrication: A Practical Guide to Semiconductor Processing", Third Edition, by Peter van Zant, McGraw Hill Publishing Co., 1997, ISBN 0-07-067250-4.

Although specific reference may be made in this text to the use of the method

and apparatus according to the invention in the manufacture of ICs, it should be explicitly understood that such an apparatus has many other possible applications. For example, it may be employed in the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, liquid-crystal display panels, thin-film magnetic heads, etc. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the term "reticle", "wafer" or "die" in this text should be considered as being replaced by the more general terms "mask", "substrate" and "target area", respectively.

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:-

Fig. 1 illustrates the principle of off-axis illumination;

Figs. 2(a) to 2(d) illustrate schematically the intensity distributions of different illumination modes;

Fig. 3 shows the results of calculations related to the exposure latitude for different illumination modes;

Fig. 4 is a graph showing experimental results of exposure latitude determinations for different illumination modes; and

Fig. 5 shows an apparatus for imaging a pattern onto a substrate with which the present invention can be embodied.

In optical lithography it is known to use off-axis illumination which enables smaller features to be successfully imaged. With this technique, the mask is illuminated at non-perpendicular angles which in particular improves the process latitude by increasing the depth of focus and/or contrast.

Fig. 1 illustrates this principle in which a beam of radiation 10 is incident on a mask 12 at an angle inclined to the optical axis, which is conventionally vertical and defines the z direction. The incident beam 10 is diffracted by the features on the mask 12 which are to be imaged on the wafer 14. The zeroth and two first order diffracted beams (0, ± 1) are shown in Fig. 1. Improved performance can be achieved when, for example, at least part of the zeroth order and one of the first orders, which are coherent, are captured by the projection lens 16 and used to form the image on the wafer 14.

The smaller the pitch of features on the mask 12 the larger the diffraction angle β will be. If the size of the features decreases and/or their density increases too much there will come a point at which the pupil of the projection lens system 16 can no longer capture more than one diffracted order. In a practical system there will be a range of opening angles α which determines the partial coherence of the light source and thus is very important to the figures of merit of the device, such as exposure latitude, depth of focus and proximity effects. The distribution of opening angles α can be visualised by considering the intensity distribution of the radiation source or equivalently the intensity distribution in the plane of the pupil of the projection lens system (and only looking at the zero order diffracted radiation or in the absence of mask features). Fig. 2 shows examples of different illumination mode intensity distributions (or pupil filling at the projection lens). The shaded areas indicate regions of significant radiation intensity. The distance from the centre of the pupil is related to the angle of incidence.

Fig. 2(a) illustrates a simple illumination mode characterised by the parameter σ shown by the arrow in the Figure. Values of σ are conventionally quoted as the ratio of the radius of the illumination intensity disc to the radius of the pupil and therefore take a value between 0 and 1. Fig. 2(b) shows an annular illumination mode in which the intensity distribution of the source is confined to an annulus to limit the range of angles of incidence of the off-axis illumination, it being remembered that the spatial intensity distribution at the pupil plane is related to the angular distribution at the mask plane. The annulus is characterised by the values σ_i and σ_o, which are the ratios of its inner and outer radii to the radius of the pupil.

Fig. 2(c) illustrates the intensity distribution of a quadrupole illumination mode, the use of which generally gives superior imaging results to the use of annular or disc modes. Conventionally, in using such a quadrupole configuration, it is assumed that the mask pattern to be projected is comprised of orthogonal lines along x and y axes and the illumination is oriented such that each of the four poles is situated in a respective one of the four quadrants defined by these x and y axes and their point of intersection.

However, it has been found that superior performance can be obtained using

dipolar illumination modes and this fact is utilised in the present invention.

Figure 2(d) shows an example of the illumination intensity distribution for a dipole mode. The two poles of this mode are located off the optical axis of the imaging system. For the following explanation, the two poles illustrated in Fig. 2(d) will be said to lie along the x axis and will be optimal for imaging lines parallel to the y axis, i.e. perpendicular to the axis joining the two poles (sometimes the x and y axes are referred to as horizontal and vertical, but these terms typically do not bear any relation to the orientation of the machine).

Fig. 3 shows the results of calculations of the Normalised Image Log Slope (NILS), a good indicator of the exposure latitude, for each of the four illumination modes shown in Figs. 2(a) to (d) for a range of different pitches of linear features in the y direction. In the graph of Fig. 3, the lines labelled A, B, C and D correspond to the illumination modes of Figs. 2(a) to (d) respectively. Each calculation assumes a numerical aperture (NA) = 0.7, and for the conventional mode a value of $\sigma = 0.85$ and for the annular (b), quadrupolar (c) and dipolar (d) $\sigma_o = 0.85$ and $\sigma_i = 0.55$.

From Fig. 3 it is clear that the simulated NILS (measure for exposure latitude) for dipole illumination (d) is significantly greater than that of the other illumination modes for pitches close to the resolution limit P_0.

Fig. 4 illustrates the experimentally observed exposure latitude at different pitches for the following illumination modes: annular (b), quadrupolar (c), and dipolar (d) respectively. The numerical aperture and σ values were the same as those for the simulation illustrated in Fig. 3. In Fig. 4 the same trends are observed as in Fig. 3 and clearly for pitches close to the resolution limit a dipole illumination mode (d) exhibits superior exposure latitudes.

A further advantage of dipole illumination is that it provides a superior depth of focus, when operating close to the resolution limit, than quadrupolar illumination. For 1:1 dense lines, the optimum depth of focus is achieved for quadrupolar illumination when:

$$\sigma_{centre} = \frac{1}{LW}\left(\frac{\lambda}{NA}\right)\frac{\sqrt{2}}{4}$$

and for dipole illumination when:

$$\sigma_{centre} = \frac{1}{LW}\left(\frac{\lambda}{NA}\right)\frac{1}{4}$$

where $\sigma_{centre} = (\sigma_o + \sigma_i)/2$, NA = numerical aperture, λ = wavelength and LW = line width.

Close to the resolution limit, $LW_r = \left(\frac{\lambda}{NA}\right)\frac{1}{4}$. When this is substituted above it can be seen that for quadrupolar illumination σ_{centre} larger than 1 is required to obtain maximum depth of focus, but since values of σ_{centre} greater than 1 are physically impossible, dipole illumination modes are preferred for maximum depth of focus for structure sizes close to the resolution limit.

A preferred embodiment of the method of the invention is to perform two exposures using two respective perpendicular dipole patterns. The first exposure is used to image mask features parallel to a first direction, and the second exposure using the other dipole illumination mode is used to image mask features perpendicular to the first direction.

Preferably two distinct masks are used, one for each of the exposures, and the superposition of the images of the two masks produces a single circuit pattern. As well as changing between perpendicular dipolar illumination modes and changing masks between the first and second exposures it is possible to select independently the specific parameters of the dipole illumination mode for each exposure, such as σ_o and σ_i and so on, in order to optimise the exposure for the structure sizes parallel and perpendicular to the first direction.

According to the methods described above, two dipolar illumination modes are used for consecutive exposures. However, this does not necessarily have to be the case. Typically, one dipolar illumination mode would be used to image the most critical features of the pattern in one direction and the other exposure could be performed using a quadrupolar, annular or conventional (disc) illumination mode to fill in the remaining structures. The order of the two exposures may, of course, be

reversed and indeed more than two exposures could be used to build up the single pattern, provided that one of them uses a dipolar illumination mode.

In its simplest form, for imaging horizontal and vertical lines only, the two masks will define only linear features in these directions respectively. However, for more complicated mask designs, software can be used to decompose the pattern into two distinct masks. Fourier transformation of the mask pattern can be used to highlight the most critical direction, and that exposure can be performed using a dipolar illumination mode.

A further embodiment of the present invention is to use a so-called soft dipole illumination mode for at least one of the dipole exposures. A soft dipole mode is particularly suited to imaging a pattern which includes some features which are not in the x or y directions, for example, diagonal or curved lines. Some examples of soft dipole illumination modes include a basic dipole intensity distribution as shown in Fig. 2(d) but with a weaker general background illumination across the pupil, or with a weaker central on-axis pole in addition to the two off-axis poles, or it may resemble a quadrupole illumination mode, but with two strong intensity poles and two weakerer intensity poles.

Referring to Fig. 5, a lithographic apparatus embodying the invention will now be described for repetitive imaging of a mask M (for example a reticle) on a substrate W (for example a resist-coated wafer). The particular apparatus shown here is transmissive; however, it may also be reflective or catadioptric, for example.

The apparatus comprises an illumination housing LH containing a radiation source and an illumination system for supplying an illumination beam IB. This beam passes through a diaphragm DR and is subsequently incident on the mask M which is arranged on a mask table MT , which is adjustable in position. The mask table MT forms part of a projection column PC incorporating also a projection lens system PL which comprises a plurality of lens elements, only two of which, L_1 and L_2 are shown in Fig. 5. The projection lens system images the mask M onto the substrate W which is provided with a photoresist layer (not shown). The substrate is provided on a substrate support WC which forms part of a substrate table WT on, for example, air bearings. The projection lens system has, for example a magnification M = 1/5, a

numerical aperture NA > 0.48 and a diffraction-limited image field with a diameter of, for example 22 mm. The substrate table WT is supported, for example by a granite base plate BP which closes the projection column PC at its lower side.

The substrate can be displaced in the x, y and z directions and rotated for example about the z axis with the aid of the substrate table. These adjustments are controlled by various servosystems such as a focus servosystem, for example an x, y, φ_z interferometer system cooperating with the substrate support, and an alignment system with which mask marks can be aligned with respect to substrate marks. These servosystems are not shown in Fig. 5. Only the alignment beam (with their chief rays AB_1, AB_2) of the alignment system are shown.

Each mask must be imaged a number of times, in accordance with the number of ICs to be formed on the substrate, each time on a different target area of the substrate.

The depicted apparatus can be used in two different modes:

In step mode, the mask stage MT is kept essentially stationary, and an entire mask image is projected in one go (i.e. a single "flash") onto a target area. The substrate stage WT is then shifted in the x and/or y directions so that a different target area can be irradiated by the beam IB.

In scan mode, essentially the same scenario applies, except that a given target area is not exposed in a single "flash". Instead, the mask stage MT is movable in a given direction (the so-called "scan direction", e.g. the x direction) with a speed v, so that the projection beam IB is caused to scan over a mask image; concurrently, the substrate stage WT is simultaneously moved in the same or opposite direction at a speed $V = Mv$, in which M is the magnification of the lens PL (e.g. M = 1/5). In this manner, a relatively large target area can be exposed, without having to compromise on resolution.

These processes are repeated until all areas of the substrate have been illuminated.

The apparatus embodying the invention further comprises a changer (not shown) for exchanging first and second masks M. Each target area of the substrate must be exposed twice, once imaging a first mask and once imaging a second mask.

The target areas of the entire substrate can all be exposed using the first mask and then the first and second masks are exchanged and all of the target areas of the substrate are exposed using the second mask. Alternatively, each target area can be consecutively exposed using the first and second masks before shifting the substrate stage to image a different target area using the first and second masks.

The illumination system of the apparatus embodying the invention includes means for defining the dipole and other illumination modes. It is presently preferred that diffractive optical elements, for example Fresnel lens segments and/or computer-generated holograms, are used to generate the dipole illumination, but other means, such as an apertured plate or interposed blades could be used. Preferably the illumination system includes an axicon/zoom module and other optical components such as an optical integrator. The illumination system can switch between different illumination modes for the first and second exposures and preferably the parameters of each mode, such as σ_o and σ_i are independently selectable for each exposure.

Further details of such illumination systems are disclosed in EP-A-0 687 956 and EP-A-0-949 541.

Whilst specific embodiments of the invention have been described above it will be appreciated that the invention may be practised otherwise than described.

CLAIMS

1. A method of imaging a pattern onto a substrate provided with a layer of energy-sensitive material, comprising the steps of:

performing a first exposure to image partly said pattern;

performing a second exposure to image partly said pattern,

wherein at least one of said first and second exposures is performed using an illumination mode having a substantially dipolar intensity distribution.

2. A method according to claim 1, wherein the other of said first and second exposures is performed using an illumination mode having an intensity distribution which is substantially one of: dipolar, quadrupolar, annular and disc-like.

3. A method according to claim 1 or 2, wherein a different mask is used to define the image formed by each of said first and second exposures.

4. A method according to claim 3, further comprising the step of exchanging masks between said first and second exposures.

5. A method according to any one of the preceding claims, wherein the or each dipolar illumination mode is used to image linear features of the pattern oriented substantially perpendicular to the axis joining the respective two poles of the or each dipole mode.

6. A method according to claim 5, wherein the respective mask used with the or each dipolar illumination mode exposure substantially defines only features of the pattern oriented substantially perpendicularly to the axis joining the respective two poles of the or each dipole mode.

7. A method according to any one of the preceding claims, wherein the or each

dipolar illumination mode intensity distribution comprises two relatively intense poles and further comprises one or more of: a relatively weak central pole; two relatively weak further poles; and a general relatively weak background intensity.

8. A method according to any one of the preceding claims, further comprising the step of:

changing at least one of the pole radial position, size and intensity between said first and second exposures.

9. A method according to any one of the preceding claims, wherein said first and second exposures are both performed using dipolar illumination modes and wherein the axes of the two dipolar modes are substantially perpendicular to each other.

10. A device manufacturing method comprising the steps of:

providing a substrate which is at least partially covered by a layer of energy-sensitive material;

providing at least one mask for defining a pattern; and

imaging at least part of said mask pattern onto said substrate using a method according to any one of claims 1 to 9.

11. A device manufactured in accordance with the method of any one of claims 1 to 10.

12. An apparatus for imaging a pattern onto a substrate provided with a layer of energy sensitive material, said apparatus comprising:

an illumination system for defining first and second illumination modes;

a projection system for imaging parts of said pattern defined by a mask on said substrate; and

a changer for changing between first and second masks;

wherein at least one of said first and second illumination modes is dipolar and

wherein said apparatus is arranged to image said pattern by two exposures using respective first and second illumination modes and masks

13. An apparatus according to claim 12 wherein said illumination system comprises a diffractive optical element for defining said first and second illumination modes.

ABSTRACT

LITHOGRAPHIC METHOD & APPARATUS

A method of imaging a pattern in a microlithographic exposure apparatus comprises performing two exposures, each with a different mask, the superposition of the images defined by the two masks produces the complete circuit pattern. A dipolar illumination mode is used for each exposure, the dipoles of the two exposures being mutually perpendicular. The dipolar illumination mode of the first exposure is used to image mask features parallel to a first direction, and the dipolar illumination mode of the second exposure is used to image mask features perpendicular to the first direction.

Fig. 1

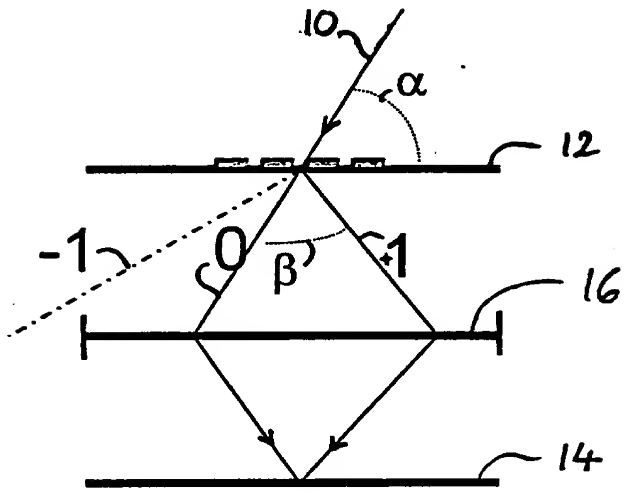

Fig. 2(a)

Fig. 2(b)

Fig. 2(c)

Fig. 2(d)

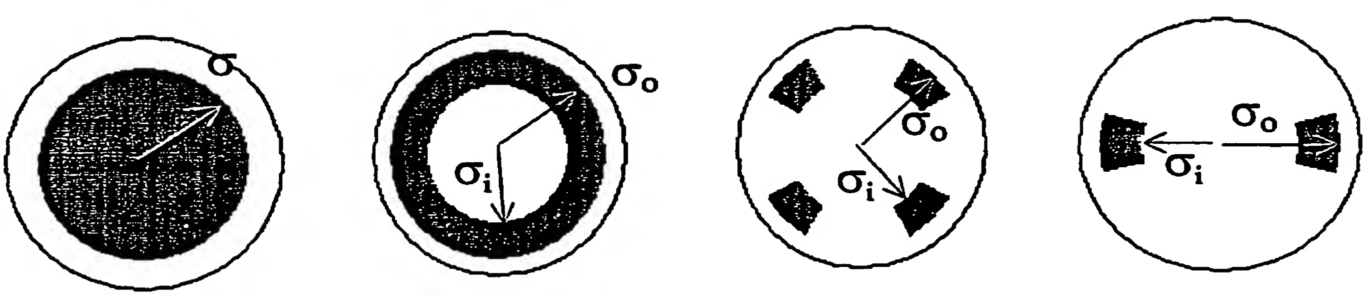

Fig. 3

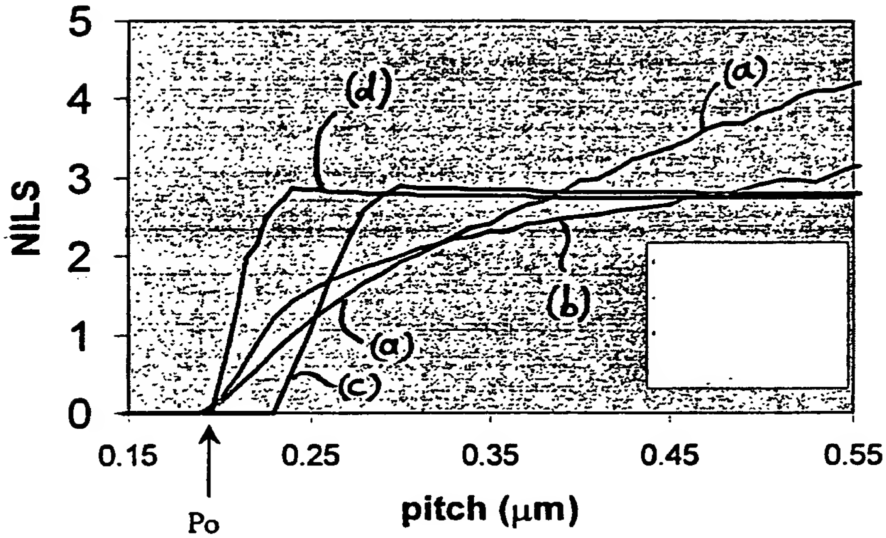
NILS
5
4
3
2
1
0
0.15
0.25
0.35
0.45
0.55
pitch (μm)
Po
(a)
(b)
(c)
(d)

Fig. 4

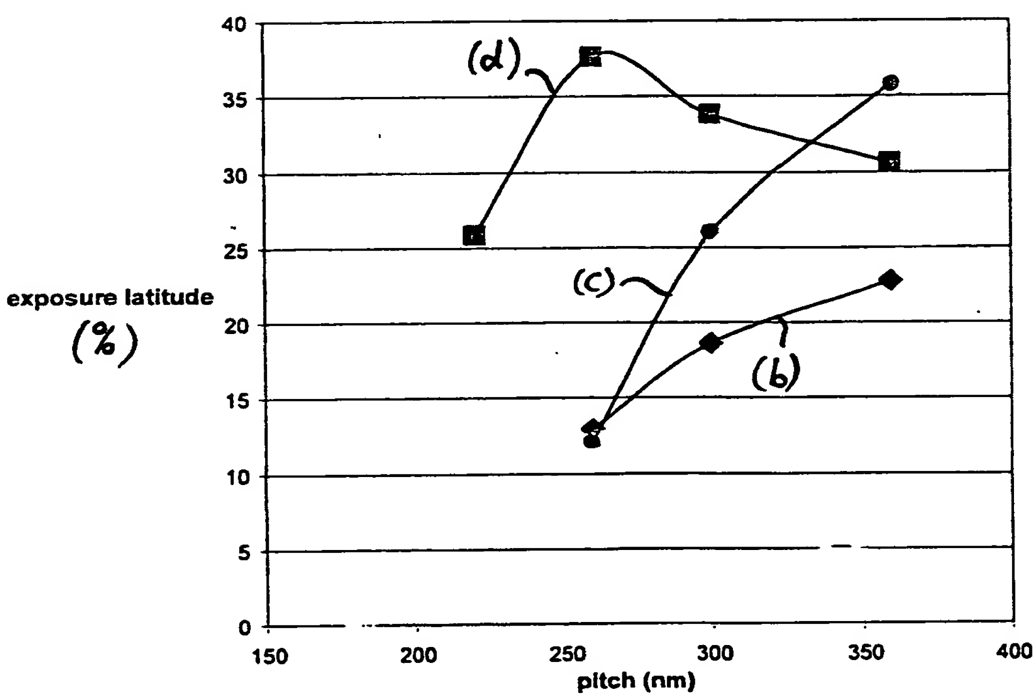
exposure latitude (%)
40
35
30
25
20
15
10
5
0
150
200
250
300
350
400
pitch (nm)
(b)
(c)
(d)

Fig. 5